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BATSE Studies of X-ray Bursters and Faint Transients
Final Report (11/1/94 - 1/31/97)

submitted by:

Jonathan E. Grindlay
Principal Investigator, Grant NAG5-2763

on behalf of:

President and Fellows of Harvard College
Office of Sponsored Research
1350 Mass. Ave.
Cambridge, MA 02138

1 Introduction

This grant supported our analysis of BATSE data from the Compton Gamma-ray Observatory carried out under observing cycles 4 and 5. Due to a delayed transition to a new grant for cycle 6 work, this grant also supported preliminary investigations now ongoing in cycle 6 on the study of hard x-ray emission from bursters and our prototype BATSE imaging survey for faint transients. In this Final Report, we summarize the Scientific Objectives of this two-part investigation (bursters and black hole transients); the Results Achieved; and finally the Papers Published.

2 Scientific Objectives of the Research

Our investigation covered two distinct classes of object: x-ray bursters and faint transients. We summarize the objectives separately for each.

Our objectives in the study of hard emission from bursters, which we have conducted jointly with MSFC and Columbia, have been to study:

1. *What is the relation between hard x-ray emission and spectral state for bursters ?.* Prior to BATSE, Ginga observations showed that the spectra of sources like 4U1608-52 became very hard with a power law type spectrum if the source was in a low state. Our objective was to followup on SIGMA studies which indicated this hard tail extended out to ~100 keV.

2. *What is the spectral break energy and is it different from that for black hole systems ?*. The presence of a hard x-ray spectral component could no longer be regarded as a unique signature of a black hole (BH)

The principal objectives in our study of faint transients have been to consider:

1. *What is the total number of BHXBs ?* Many estimates (e.g. Tanaka and Lewin 1995 and references therein) estimate on the basis of simple arguements such as the SXT detection rate a total population of BHLMXBs in the Galaxy to be $\gtrsim$ 300-1000. If BATSE cannot find the predicted fainter systems, have the optical distances been systematically under-estimated or are the peak luminosities typically fainter ?

2. *What is the formation rate of BHXBs ?* Clearly the total number, or constraints, is needed to understand if models for the formation of BHXBs vs. NSXBs which predict large numbers of BHLMXBs are correct.

3. *What are the characteristic spectra and lightcurves of SXTs ?* A search for faint BHXBs with BATSE (and future more sensitive surveys) is crucial for comparison with ASM or WFC searches (RXTE and future ASMs) which will operate in the 2-10keV band, typically. Recent WFC detections of $\sim$10 mCrab transients in the galactic bulge region by SAX may suggest a much higher rate of either fainter or softer transients.

4. *What are the characteristic recurrence times for SXTs ?* If the BATSE detection rate is much lower than predicted, is the recurrence time much longer than the small-N statistics would now indicate ? This of course directly affects questions 1 and 2 above as well as the outburst models. It is of particular interest to search for "mini"-outbursts of the nearby bright systems (e.g. A0620-00), which might be expected to be more detectable in the hard x-ray band than soft band for the source in an intermediate or low state.

3 Results Achieved

Considerable progress was achieved over the duration of this grant in our continuing study of hard x-ray emission from x-ray bursters and from faint x-ray transients. Our investigation makes use of occultation data from the BATSE experiment on the Compton Gamma Ray Observatory and is being carried out in collaboration with the BATSE team at the MSFC as well as (for the burster study) a group (Ford, Kaaret and Tavani) at Columbia. In the following paragraphs, we summarize results achieved first for the study of x-ray bursters and then for the study of transients.

Study of X-ray Bursters

We have shown that x-ray burst sources, or low mass x-ray binaries (LMXBs) containing a neutron star accreting from a low mass companion, can be relatively intense hard x-ray

(20-200 keV) sources when their accretion rate is relatively low. This work follows up, and extends significantly, earlier work conducted with the French/Russian SIGMA telescope on the GRANAT Observatory by Didier Barret, the post-doctoral fellow supported (in part) on this grant at Harvard. Our analysis of BATSE data on x-ray bursters has been carried out primarily by Barret and also by graduate student Peter Bloser, who has also received partial support from this grant.

We have achieved a number of our original objectives, although of course considerable followup work remains:

1. We have shown that x-ray bursters do indeed have significant hard x-ray emission, thereby confirming and greatly extending the SIGMA results. In particular we have demonstrated that the bursters 4U1608-52 and 4U0614+09 have hard x-ray spectra extending out to break energies of ~50-70 keV and flux significantly (anti-)correlated with their soft x-ray emission.

2. We have shown that ultra-compact systems, 4U1820-30 (11 min binary) and 4U1916-05 (50 min binary) are not strong hard x-ray emitters. They were not detected in either our BATSE or OSSE studies, whereas particularly for 4U1916-05 the luminosity similarity to 4U0614+09 would suggest it should have been. The implications for the hard x-ray source emission region in bursters is an interesting project for followup investigation.

Our burster studies have been conducted in collaboration with the Columbia group (E. Ford, P. Kaaret and M. Tavani). The collaborative effort carried out under this grant has focussed on the study of the 4U0614+09 system, for which we found the BATSE hard x-ray emission was significantly anti-correlated with the RXTE medium x-ray flux. Later work on this source (cycle 6) has focussed on QPOs and will be described in reports for the activity carried out in cycle 6 under the new grant.

Study of Faint X-ray Transients

Our study of faint x-ray transients is aimed at detection and study of faint (100 mCrab) transient x-ray sources that likely contain black holes. The transients detected thus far by BATSE are typically very bright ($\gtrsim$ 1 Crab in peak flux) and are found to be relatively close (distances typically $\lesssim$ 3 kpc). Our survey of BATSE data is designed to pick out the fainter more distant sources. This study will constrain the number of black hole systems in the Galaxy. Thus far we have discovered at least one new source (GROJ1849-03), detected the hard x-ray emission from another suspected black hole transient (4U1630-47) and have conducted an extensive survey of both known sources and blank fields containing no known transients. These results were achieved in our cycle 4 and 5 programs.

In cycle 6 we are conducting a pilot survey of the full galactic plane using wide-field (24° × 24°) BATSE images and a newly developed automated BATSE image analysis system. This CFA BATSE Image Search (CBIS) system has occupied much of effort over the end of our

cycle 5 and start of cycle 6 programs which were supported by this grant. The CBIS system allows a semi-automated search of thousands of images as needed for the full analysis of the BATSE dataset. An optimized CBIS system, with smaller fields of view ($12^\circ \times 12^\circ$) and consequently more fields (420) to cover the galactic plane has been proposed for a full cycle 7 investigation.

Overall, we have achieved the following results on faint transients for our work supported by this grant:

1. We have discovered hard x-ray emission from a previously suspected black hole candidate (BHC) system, 4U1630-47, and constrained its long-term (600d) outburst ephemeris.

2. We have discovered a new hard x-ray transient, GROJ1849-03, which may be a Be system with a black hole companion. Alternatively, it may (still) be confused with one of the previous transients (including a pulsar) discovered by Ginga; higher spatial resolution studes are needed.

3. Our early results for the galactic plane survey suggest the number of faint transients in the Galaxy may be less than expected from simple scaling arguements based on the detection rate of bright transients (by Ginga and BATSE) and estimates for the distances derived from optical studies.

4. We have developed a powerful BATSE image search system (CBIS) to conduct a much more sensitive and complete galactic plane survey.

4 Papers Published

Although much of the work from this grant is being carried on into cycle 6 under the followup grant, and more is proposed for cycle 7, the NAG5-2763 grant activity for cycles 4-5 (and part of 6) has resulted in a number of publications. Below we list the papers published, all in refereed publications, for the burster work and then the faint transients survey work.

Following are papers on our study of x-ray bursters which report results achieved in this study:

1. "BATSE Observations of Hard X-ray Emission from X-ray Bursters", D. Barret, J. Grindlay, P. Bloser, S. Zhang, G. Fishman, B. Harmon, W. Paciesas, P. Kaaret, M. Tavani, and E. Ford, *Astronomy and Astrophysics, Supplement Series*, 120:121-127 (November, 1996).

2. "BATSE Observations of Two X-ray Bursters: 4U1820-30 and 4U1915-05", P. Bloser, D. Barret, J. Grindlay, S. Zhang, B. Harmon, G. Fishman, W. Paciesas, E. Ford, P. Kaaret, M. Tavani *Astronomy and Astrophysics, Supplement Series*, 120: 275-278 (November, 1996).

3. "Low State Hard X-ray Outburst from the X-ray Burster 4U1608-522 Observed by BATSE/CGRO", S. Zhang, B. Harmon, W. Paciesas, G. Fishman, J. Grindlay, D. Barret, M. Tavani, P. Kaaret, P. Bloser, E. Ford and L. Titarchuk, *Astronomy and Astrophysics, Supplement Series*, 120: 279-282 (November, 1996).

4. "Anticorrelated hard/soft x-ray emission from the x-ray burster 4u 0614+091", E. Ford, P. Kaaret, M. Tavani, B. A. Harmon, S. N. Zhang, D. Barret, J. Grindlay, P. Bloser, and R. A. Remillard, *Astrophysical Journal Letters*, 469:L37–+, (September, 1996).

Following are papers published or submitted for publication which report development of CBIS and preliminary results achieved for the faint transients survey:

1. "BATSE Imaging Survey of the Galactic Plane", J. Grindlay, D. Barret, P. Bloser, S. Zhang, C. Robinson, and B. Harmon, *Proc. 2nd INTEGRAL Workshop*, ESA SP-382, in press (1997).

2. "BATSE Survey for Faint Transients and Black Hole Candidates", J. Grindlay, D. Barret, P. Bloser, S. Zhang, G. Fishman, B. Harmon, and W. Paciesas *Astronomy and Astrophysics, Supplement Series*, 120: 145-148 (November, 1996).

3. "BATSE Observations of the Ultra-soft X-ray Transient 4U1630-47", P. Bloser, D. Barret, J. Grindlay, S. Zhang, B. Harmon, G. Fishman, and W. Paciesas *Astronomy and Astrophysics, Supplement Series*, 120: 191-195 (November, 1996).

4. "Periodic Transient Hard X-ray Emission from GROJ1849-03", S. Zhang, B. Harmon, W. Paciesas, G. Fishman, M. Finger, C. Robinson, B. Rubin, J. Grindlay, D. Barret, M. Tavani, P. Kaaret, P. Bloser, and E. Ford *Astronomy and Astrophysics, Supplement Series*, 120: 227-230 (November, 1996).